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Division 11

NATIONAL DEFENSE RESEARCH COMMITTEE

of the

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

OSRD No. 5154

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DIVISION 11
NATIONAL DEFENSE RESEARCH COMMITTEE
of the
OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
OXYGEN PLANT DEVELOPMENT
EMPLOYING REGENERATIVE CHEMICALS

to
March 16, 1945
by
W. E. Lobo and C. Bockius

Report OSRD No. 5154

Copy No. 33

Date: May 31, 1945

Copy No.

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- 8-24 OSRD Liaison Office
- 25 Air Corps Liaison Officer with NDRG
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- 26-27 Chief, Bureau of Ships, Attn: Capt. R. V. Meinschmidt
- 28 Chief, Bureau of Aeronautics, Attn: Capt. J.E. Sullivan
- 29 Director, Naval Research Laboratory
- 30 Aero Medical Research Laboratory, Wright Field
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- 42-43 Dr. J. H. Wolfenden
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Division 11

NATIONAL DEFENSE RESEARCH COMMITTEE
of the
OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

Section 11.1

OXYGEN PLANT DEVELOPMENT
EMPLOYING REGENERATIVE CHEMICALS

Service Directive NL-B42; NS-117

Endorsement (1) from H. M. Chadwell, Chief Division 11
to Dr. Irvin Stewart, Executive Secretary of the National
Defense Research Committee. Forwarding report and noting:

"This report covers oxygen generating plants
utilizing the absorbent "Salcomine." The
plants were designed by the M. W. Kellogg Co.
and such construction as took place was done
by the American Machine Defense Corp. The
shipboard unit, though completed, was super-
seded by one designed and constructed by the
A. D. Little Co. (Now installed on a Naval
Vessel). The truck-mounted units were early
abandoned as non-competitive with liquifaction
units. Other units were largely experimental.
This work was completed about two years ago."

This is a progress report under Contract 11-244, OEM-r-365
with M. W. Kellogg Co. and a final report under Contract
11-261, OEMsr-499 with American Machine Defense Corporation.

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Final Report
On
Oxygen Plant Development
(Employing Regenerative Chemicals)
To
National Defense Research Committee
By
The M. W. Kellogg Company
Contract No. OEM-sr-365
And
American Machine Defense Corporation
Contract No. OEM-sr-499

Submitted by:

Walter E. Lobo
Walter E. Lobo
for
The M. W. Kellogg Company

C. Bockius
C. Bockius
for
American Machine Defense Corporation

March 16, 1945

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SUMMARY

This report contains a description of the work performed by The M. W. Kellogg Company and the American Machine Defense Corporation for the National Defense Research Committee in the development of oxygen plants employing regenerative chemicals.

In addition to a chronological description of each plant or study involved in the program, the report contains a bibliography of correspondence, memoranda, reports and specifications dealing with equipment details and operating experiments.

Detailed process calculations and a list of all drawings are supplied for the Shipboard (C-2) unit, the only complete unit fabricated by the contracting companies. Process calculations and detailed designs are not furnished for plants which were studied but not erected.

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GENERAL DESCRIPTION OF WORK

Preliminary Activities

In December, 1941, exploratory discussions were held between representatives of the National Defense Research Committee and The M. W. Kellogg Company. In the following month, January, 1942, Kellogg formally agreed to become the central engineering agency for the NDRC oxygen program. On January 27, Kellogg representatives attended a general conference on oxygen problems convened at Massachusetts Institute of Technology under the sponsorship of the NDRC oxygen section.

At this meeting it was made clear that high hopes were entertained for mobile oxygen plants based on the use of the regenerative chemical "Salcomine". Preliminary engineering studies by Dr. Gilliland's group at M.I.T. had indicated that attractive yields of oxygen could be absorbed from the atmosphere by beds of Salcomine undergoing what then seemed to be moderate changes of temperature and pressure.

During February negotiations were carried on between the NDRC and the American Machine & Foundry Co., which finally culminated in the granting of a contract to the American Machine Defense Corporation, a newly formed subsidiary of American Machine & Foundry Co. Kellogg meanwhile began process and equipment studies for mobile truck Salcomine units producing 1000 cu. ft./hr of high purity oxygen. The difficulties to be overcome in this work were materially and unexpectedly augmented by the realization that mobile units for field service would be required to operate in all climates without dependence on external agents other than the local atmosphere and engine fuel.

This requirement was made only too clear in a discussion between Kellogg representatives and Capt. Beverly (U.S. Army Engineer Corps) on February 6. The mobile unit was thus seen to require not only air and oxygen compressors (driven by gasoline engines) but also heating and cooling devices to move the Salcomine through the necessary temperature range. Atmospheric air became the basic cooling medium while all heat had to be obtained from engine fuel.

To establish designs which would meet the most severe atmospheric conditions that might be encountered in all foreseeable combat areas, it was decided to design all ground units for operation in air at 120°F with a dew point of 90°F, a condition which might occur in Pacific Islands lying near the

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Equator.

The Salcomine program also visualized the development of units for use on shipboard and in long-range bombing planes. A ground unit capable of being separated into relatively small sections for transportation by plane to remote localities (so-called "air transported" unit) was also contemplated, but at the period in question, February, 1942, greatest emphasis was being placed on mobile truck units for use by the Engineer and Air Corps.

A then-recent development by the M.I.T. group further restricted the design of the equipment. Most reaction vessel designs under discussion involved fixed beds of powdered Salcomine surrounding coils or pipes for the heating and cooling fluids. In view of the poor heat-conducting properties of Salcomine, it would have been highly desirable to employ heat transfer tubes fitted with fins, ribbons or other extended surfaces - thereby greatly shortening the time required to heat or cool the powder through a specified temperature change. Unfortunately the powder, as then prepared, packed into a very rigid cake in the course of operation. It was therefore agreed that it would be almost impossible to remove Salcomine from a reactor fitted with extended surface tubing. Reactor designs were to be drastically restricted to those containing plain tubing arranged for easy cleaning.

At the same time, Kellogg undertook discussions with the Clark Brothers Co. on the specifications for the air and oxygen compressors in the proposed Salcomine units.

During March designs were prepared in some detail for two mobile truck units. These designs differed from one another principally in the shape and internal tube arrangements of the heating surfaces. Both proposed to supply heating and cooling by a continuously circulating refrigerant which was to act as a heating medium at high pressure and a cooling medium at low pressure.

However, when preliminary mobile unit designs were completed it was apparent that Salcomine units would be heavier, larger and more complex than units of the same capacity producing oxygen by the employment of liquid air cycles. Thus, it was estimated that a chemical truck unit producing 1000 cu.ft./hr. would weigh about 8 tons (exclusive of truck or trailer) and would require engines developing about 180 horsepower. Corres-

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ponding liquid air units, it was believed, would weigh about 5 tons (exclusive of truck or trailer) and would require about 80 horsepower.

On March 20, at a meeting with the NDRC oxygen staff, Kellogg representatives proposed the abandonment of the Salcomine process for mobile truck units. During this meeting it was pointed out that recent laboratory work at M.I.T. indicated that an adiabatic unit might ultimately be realized. This unit would operate over a narrow temperature range using very high pressure air (600 psi or greater) in the absorption step. Such an arrangement would dispense with the elaborate heating and cooling apparatus required for lower pressure operation.

Accordingly, it was agreed to suspend all further work on truck units until a laboratory evaluation of the adiabatic cycle had been made. Meanwhile, studies of units for generating oxygen on shipboard were to be inaugurated. These units would depend on ship supplies of steam and cooling water, and would therefore, be much smaller and simpler than the completely self-contained truck units.

Shipboard Unit (C-2)

On March 26, Kellogg and NDRC representatives conferred in Washington with officers of the Bureau of Ships (USN) to establish the major features of the shipboard unit. It was agreed at that time to construct a unit similar to those previously proposed for the truck units, but relying on supplies of steam and cooling water from external sources. In addition, the unit would be designed to generate oxygen at 20 psig pressure which was then considered adequate for cutting torch use and which would obviate the need for an oxygen compressor. It was decided to employ reactors containing flat, removable coils for the heat transfer fluids with the powder bed surrounding the coils.

Drawings and specifications for most of the necessary equipment in the shipboard unit (type C-2) were delivered to American Machine Defense by the end of March. These were promptly forwarded to the Whitlock Manufacturing Company at Hartford, Connecticut, which had undertaken to fabricate the pressure vessels and erect the unit as sub-contractors to American Machine Defense.

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The general procedure followed by the participating companies during the ensuing weeks was:

- A) Kellogg made process calculations; prepared detailed flowsheets; designed and prepared assembly drawings for pressure vessels and other items; prepared detailed specifications; prepared detailed piping drawings;
- B) American Machine Defense, upon receipt of the foregoing material from Kellogg, reviewed all designs and suggested improvements on the basis of their manufacturing experience; issued purchase orders for all materials and parts; arranged for shipment and delivery of all items to their plant or to Whitlock; prepared shop detail drawings; arranged with American Machine & Foundry Co. for fabrication of all parts requiring close machine work; shipped to Whitlock all items delivered to or fabricated in their plant;
- C) Whitlock took delivery and inventoried all items required in the assembly of the unit; fabricated the pressure vessels and other heavy pieces in accordance with instructions from Kellogg and American Machine Defense; constructed supporting structures; assembled piping; erected the entire unit; supplied utilities from their plant system.

As originally designed in March, 1942, the unit was to operate on air at 275-300 psi pressure. At about this time the M.I.T. group undertook a study of the decline in activity experienced by the Salcomine in use. It was soon noted that, when operated at these pressures, the chemical lost most of its activity in much fewer cycles than it did when operated at about 100 psi. By then, construction of the unit was well advanced and it was decided to leave the design unchanged but to operate at air of about the latter pressure. Under these circumstances, with a large air supply available, process calculations indicated that the unit would produce only 600 cfh instead of the 1000 cfh which was predicted for the higher pressure operation.

It was also discovered that generation of oxygen under 20 psi pressure (as contemplated in the meeting of March 26)

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would be very harmful to the chemical activity of the Salcomine. Accordingly, during the month of June it was decided to desorb the oxygen from the reactors at atmospheric pressure and to employ a 2-stage oxygen compressor to raise the final oxygen pressure to 150 psi (which was felt to be necessary for under-water cutting work). A compressor for this service was ordered at that time from Clark Brothers.

The construction of the unit was greatly delayed by many shortages of critical materials and components, a condition which hampered the entire war production program during most of 1942. As originally designed for shipboard service, the reactors were to be cooled by circulation of sea water through the internal coils. These were to be of cupro-nickel alloy and were to be connected by headers made from cast Monel metal. It soon developed that those materials were almost unobtainable under the priority ratings then assigned to the project. During May the unit was drastically revised to permit the use of more abundant materials, with a consequent loss in operating flexibility. Fresh water was to be used as the coolant; the cupro-nickel tubes were replaced by brass; and the Monel castings by built-up assemblies of carbon steel. For marine use, the fresh water would be cooled in a cupro-nickel, shell-and-tube exchanger against a stream of sea water. This scheme merely shifted the critical alloys from the reactors to the heat exchanger, but resulted in an overall saving in time required to develop the unit. It was realized that a considerable quantity of test work would be required at a shore station before the unit could be installed on a ship, and it was clear that the time required for the shore testing (which would be done with fresh water as the coolant) would be ample for obtaining the cupro-nickel exchanger.

During June and July it became evident that operations were moving very slowly at the Hartford plant of the Whitlock Co. This was not surprising because Whitlock was carrying an extremely heavy production schedule of equipment for the Navy and the Rubber program. This condition, combined with the acute shortage of good mechanic and engineer personnel, made it impossible for Whitlock to give the experimental oxygen unit the close attention which it required.

In August, therefore, American Machine Defense stationed one of its development engineers at the Hartford plant with instructions to push ahead the fabrication of the C-2 unit. This arrangement produced a noteworthy improvement, but to expedite matters further, Kellogg placed a member of

its Operating Department at Whitlock to cooperate with the American Machine Defense representative in hastening the job. It was then learned that certain key components for the unit had been incorrectly or carelessly fabricated and were unusable. To eliminate further cases of this sort, Kellogg inspectors made regular visits to the job during ensuing weeks and passed "official" judgment on current production.

Of the four reactors employed in the complete unit, one was placed in operation on November 12, to be joined by a second reactor the following day. The third reactor went on stream on November 28, and the last reactor was ready by December 14. Exhaustive studies were made to establish the best operating conditions, but in spite of all efforts, the maximum production was only 300-400 cfh. This low production was attributed to several factors:

- A) Poor heat transfer characteristics of the plain brass tubing used to heat and cool the Salcomine.
- B) Insufficient air supply to the reactors. Because of limitations in the Whitlock compressed air system, the unit usually received 4000-5000 cfh at 80-85 psi instead of the expected 8500 cfh at 90-100 psi.

The unit was given a preliminary demonstration in December before representatives of the Bureau of Ships and the NDRC. At that time plans were made for a more formal showing as soon as all mechanical work was complete. It was also agreed that Kellogg would construct a scale model of a proposed shipboard unit, similar in general to the existing C-2 unit but rearranged and revised to occupy minimum space. This model was intended to demonstrate to Navy officials the layout possibilities which might be attained in future units.

During January the oxygen compressor was received from Clark Brothers. It was installed with an electric motor drive and, after a few preliminary adjustments, was found to give satisfactory service.

In order to improve the heat transfer characteristics of the reactors, it was decided to install finned coils in place of the existing smooth coils. It will be recalled that the smooth coils had originally been selected to facilitate

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removal of caked Salcomine from the reactors. During the Summer of 1942, however, the Rumford Chemical Works had developed a grade of Salcomine powder which did NOT form solid cakes in use. Since this non-caking material was now available for use in the C-2 unit, it became practical to employ finned coils to improve heat transfer. Such coils were designed by Kellogg and ordered by American Machine Defense from the Rome-Turney Company at Rome, N.Y.

On January 20, 1943, the unit was formally demonstrated to representatives of the Bureau of Ships and the Office of the Coordinator of Scientific Research and Development (USN), in the presence of the NDRC oxygen staff and personnel of the participating contractors. Bureau of Ships' representatives expressed great interest in the unit and urged that the finned coils (then on order) be fabricated and installed with all possible speed. It was stated that when this work was complete, the unit should be prepared for shipment to an overseas base where it would be placed in regular operation to augment a critical oxygen shortage.

During February, one set of the new finned coils was received and placed in service. Performance in the reactor was greatly improved and it was calculated that, when the entire unit was so equipped, production would easily reach 500 cfh even with the restricted air supply available. The remaining finned coils were received and installed during March.

By this time it became clear that the Bureau of Ships was not going to place the unit in immediate service. All equipment was therefore dismantled and shipped to the Central Engineering Laboratory of the Oxygen program at the University of Pennsylvania. It was agreed that the unit would be reassembled there if Navy interest revived.

The delivery of the unit, on April 16, 1943, to the Central Engineering Laboratory terminated the work of Kellogg and American Machine Defense on the development and design of shipboard oxygen plants.

Shipyard Unit (C-4)

In the early part of 1942 a critical shortage of oxygen existed in some of the recently established shipyards in various parts of the country. During March of that year the NDRC requested Kellogg to prepare preliminary designs for a Salcomine unit to generate oxygen in shipyards, drawing utilities from local supplies. Kellogg accordingly proposed a slight modifi-

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cation of the shipboard unit for this service. Specifications, flowsheets and drawings for this unit were submitted to the War Production Board, the Shore Facilities Section of the Bureau of Ships and the Office of the Coordinator of Scientific Research and Development of the Navy Department.

No further action was taken by Kellogg.

Mobile Truck Units (C-1A and C-1C)

As was previously stated, active design work on these units was temporarily suspended in March, 1942, pending further laboratory studies at M.I.T. During the next two months further experiments made it clear that adiabatic processes would not prove advantageous for the mobile truck units. In May, therefore, process studies were resumed on truck units similar to the types outlined in February and March. Kellogg continued to believe that the Salcomine process was not suitable for truck use in any form, but the project was continued at the request of the Army Air Corps and the NDRC. This decision was motivated by the realization that many aspects of the military oxygen program were not then completely clarified and that, as yet, no possible research lead could safely be neglected.

The prime contract for fabrication and assembly of these units was placed with the Independent Engineering Company at O'Fallon, Ill. A sub-contract for pressure vessel fabrication was arranged with the Whitlock Manufacturing Company. Each unit was to be mounted on two trailers, one containing the Salcomine reactors and the other carrying the engines and compressors. It was further agreed that the compressor-engine trailers for each unit would be fabricated and assembled by Clark Brothers as sub-contractors to Independent Engineering.

Detailed design and purchasing work was begun at once. Due to the usual delays in obtaining critical materials and components, many months elapsed before assembling operations could be started. In the meantime, the development of mechanical units in other parts of the Kellogg organization proceeded very favorably while the original disadvantages noted in the Salcomine units persisted despite prolonged research efforts in many quarters.

At length, the Army Air Corps agreed to the cancellation of these units. On November 24, the NDRC ordered its contractors to terminate their activities and ship any non-returnable or partly fabricated components to the Central

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Engineering Laboratory at the University of Pennsylvania.

Kallogg's work in connection with cancellation and return of materials was concluded in February, 1943.

Bombing Plane Unit

During May, 1942, numerous process and equipment studies were made in an effort to develop a small Salcomine unit which would deliver 100 cfh when operated in a bombing plane at high altitude.

With the information then available, all designs appeared unattractive because of weight and size requirements. The project was accordingly tabled, pending the development of more active chemical adsorbents for this very exacting service.

Several months later, work was resumed by the M. I.T. group and, after numerous studies of reactor designs and other variables, was permanently dropped.

Medical Corps Unit

During May, 1942, numerous process and equipment studies were made in an effort to develop a small Salcomine unit to meet the requirements of the Army Medical Corps. Due to the difficult heat and pressure requirements placed upon self-contained units, it was agreed that the Salcomine process was not attractive for the service contemplated. The project was dropped.

Air Transported Unit (C-5)

Detailed process studies for this unit were undertaken in September, 1942. In addition to the usual requirements confronting self-contained units, this unit was to be capable of rapid field assembly from packages not exceeding 20" x 34" x 50". Pieces of equipment and cases smaller than these dimensions were considered to be suitable for transportation by air to remote localities.

A design was developed, based on a group of packages of the allowable size, in which each package performed only a few of the functions demanded of the overall unit. The main package contained two Salcomine reactors which were to be heated and cooled by recirculation of gas through the powder

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beds. The recirculating gases were heated, or cooled, in exchangers which contacted a circulating refrigerant system not unlike that proposed for the mobile truck units.

Preliminary information on this plan was presented to the NDRC on October 8, 1942. Kellogg took no further action on the project.

Fluid Powder Study

During the preliminary process studies made in February, 1942, Kellogg investigated the possibilities of applying the fluid powder technique to the Salcomine process. This new method for handling gases and solids was then finding very wide application in the expanding aviation gasoline program, and it seemed reasonable to consider its utility in the task at hand for the NDRC.

Preliminary designs did not seem attractive because of the very large pressure changes to which the fluidized gas-powder mixture would be subjected. It was felt that no further process studies should be made until some laboratory work was done to determine whether or not the oxygen-making process would actually occur under fluid powder conditions.

In July of the same year, Kellogg submitted to the NDRC an estimate covering the cost of erecting and operating a Salcomine fluid powder pilot plant at the Kellogg Laboratories in Jersey City, N.J.

The proposal was not authorized and Kellogg did no further work on the matter.

Miscellaneous Process Studies

Kellogg prepared engineering appraisals of several process and equipment schemes developed by other participants in the NDRC program. Among these were:

A) Salcomine-Oil Suspension

Preliminary studies were made by the DuPont Company of a plant circulating suspension of Salcomine in white oil. A flowsheet for a truck unit prepared by DuPont was appraised by Kellogg. It was con-

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cluded that such a unit would not compare favorably with liquid air units of the same capacity.

B) Screw-Conveyor Unit

Brief engineering studies were made by Kellogg of a unit developed at the University of Iowa. This unit employed Methomine (a then-new Salcomine derivative) which was moved through the process cycle by a system of screw conveyors. The unit was not recommended for further consideration.

C) Tessie duMotay Process

Kellogg inspected the pilot plant erected by DuPont for their modification of this process. After a review of energy and equipment requirements it was concluded that the process might be applicable for shipyard units. It was not considered suitable for truck or shipboard service. Kellogg submitted a report on these findings to the NDRC on December 16, 1942. No further action was taken.

Miscellaneous Shop Work

In addition to activities previously described, the American Machine Defense Corporation ordered and supervised the execution of several miscellaneous fabrication jobs in the shops of the parent company, the American Machine & Foundry Company.

Among these were:

- A) Fabrication of several Collins-type heat exchangers for the mobile mechanical units and for research studies at Yale University.
- B) Automatic timers (according to Kellogg designs) for use on the Salcomine and mechanical truck units.

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BIBLIOGRAPHY

Detailed information concerning the work summarized in this report will be found in the following tabulation of correspondence and reports (arranged by type of unit or project):

Shipboard Unit (C-2)

- A) M. W. Kellogg Company equipment specifications dated April 23, 1942(revised June 1, 1942)
- B) M. W. Kellogg Company progress reports to NDRC (July 15, 1942 through April 15, 1943).
- C) M. W. Kellogg Company Report "Small Oxygen Plants (Salcomine Process) for Shipboard Installation", January 19, 1943.

Shipyard Unit (C-4)

M. W. Kellogg Company equipment specifications dated April 20, 1942(revised May 14, 1942).

Mobile Truck Units (C-1A and C-1C)

M. W. Kellogg Company progress reports to NDRC (June 15 through December 15, 1942)

Bombing Plane Unit

M. W. Kellogg Company letter from Walter E. Lobo to C. C. Furnas at NDRC Washington Office, May 25, 1942.

Air Transported Unit (C-5)

M. W. Kellogg Company letter from Walter E. Lobo to C. C. Furnas at A. D. Little Co. New York City Office, October 8, 1942.

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BIBLIOGRAPHY CONTD.

Fluid Powder Study

M. W. Kellogg Company letter from Walter E.
Lobo to C. C. Furnas at NDRC Washington
Office, August 6, 1942.

Tessie duMotay Process Study

M. W. Kellogg Company letter from Walter E.
Lobo to E. P. Stevenson at A. D. Little
Co., Cambridge, Mass. Office, December
19, 1942.

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PROCESS CALCULATIONS

Basis of Design (As of March 10, 1942)

Output - 1000 CFH Oxygen at STP (60°F, 1 atm)

Number of Reactors - 4

Cycle Time on Each Reactor:

Absorption	3' 0"
Evacuation	20"
Heating and Desorption	5' 40"
Valving	5"
Cooling	2' 50"
Valving	5"
	<hr/> 12' 00"

Absorption Pressure	250 lbs gage
Desorption Pressure	Atmospheric
Absorption Temperature	35°C - 95°F
Desorption Temperature	100°C - 212°F

% Oxygen in Compound After Absorption	3.65%	based on weight of compound
% Oxygen in Compound Before Absorption	0.30%	
Yield	3.35%	(From data in letter of December 4, 1941 from E.R. Gilliland to C.C. Furnas)

% Oxygen Desorbed 93% of Oxygen Absorbed

True Density of Salcomine 1.5
Packed Density of Salcomine 0.7

Exit Gas Rate 4 CFH per 40.7 GHS of Salcomine at
25°C and 1 atm

Compound Required

Weight of Oxygen Produced = $\frac{1000 \times 32}{379}$ = 2.64 mols/hr x 32 = 84.5 lbs/hr

Assuming 3% Loss in Voids, etc. O₂ Desorbed = $\frac{84.5}{1.03}$ = 87.0 lbs

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Process Calculations
C-2 Unit
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Compound Required Contd.

Frequency - 5 complete cycles/hr

$$\text{Weight of compound} = \frac{87.0}{5} \times \frac{100}{3.35} = 519 \text{ lbs of unsaturated compound}$$

$$= 519 \times 1.045 = 542 \text{ lbs of saturated compound}$$

$$\text{Compound per reactor} = \frac{542}{4} = \underline{135} \text{ lbs}$$

Air Required (for absorption at 250 lbs/sq.in. and original cycle)

Exit gas rate = 4 CFH per 40.7 GRS of sat. Salcomine at 25°C

$$\text{Total exit gas} = \frac{135 \times 454}{40.7} \times \frac{520}{537} = 5820 \text{ CFH}$$

$$\text{Air input} = 5820 + 1000 \text{ CFH O}_2 = 6820 \text{ CFH @ 60°F, 1 atm}$$

$$\text{O}_2 \text{ yield} = \frac{1000}{6820 \times 2.1} 100 = \underline{70\%}$$

Reactor Design

28 flat spiral coils of 9/16" OD copper tubing, turns 7/8" between centers with the horizontal coils 0.76" apart.

Fraction Void in Salcomine

packed density 0.7
true density 1.5

$$\text{Fraction void} = 1 - \frac{\text{packed density}}{\text{true density}} = 1 - \frac{0.7}{1.5} = 0.53$$

Estimated Weight of Reactor

Coils and coil fittings	185 lbs
Flanges and bolts	160 lbs
Top head	60 lbs
Bottom head	50 lbs
Bottom header	75 lbs
Top header	30 lbs
Shell, core, screens	<u>145 lbs</u>
	705 lbs

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Process Calculations
C-2 Unit
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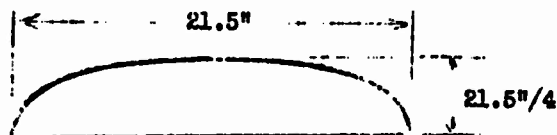
Effective Compound in Reactor

Reactor Volume

Shell 24.75" ID x 21.375 h
3.00" OD core

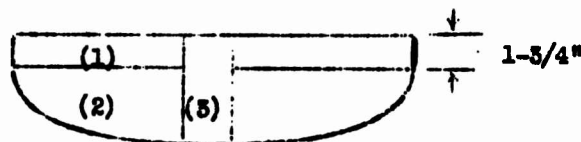
$$(24.75^2 - 3^2) \frac{\pi}{4} \times 21.375 = 10,140 \text{ cubic inches}$$

Lower Head



$$\text{Vol. of head} = \frac{1}{2} \frac{4}{3} \pi a^2 b \text{ where } b = \frac{21.5}{4} \text{ and } a = \frac{21.5}{2}$$

$$V = \frac{2\pi}{3} \left(\frac{21.5}{2} \right)^2 \left(\frac{21.5}{4} \right) = \frac{\pi}{24} (9938) = 1300 \text{ cubic inches}$$



$$\text{Vol. of cylindrical part (1)} = \frac{\pi}{4} (24.75)^2 \times 1.75 = 842 \text{ cu. inches}$$

$$\text{Vol. of part (3)} = \frac{\pi}{4} 9 \times 7.25 = 51.2 \text{ cu. inches}$$

$$\text{Total vol.} = (1) + (2) - (3) = 1300$$

$$\begin{array}{r} + 842 \\ \hline 2142 \\ - 51 \\ \hline 2091 \end{array} \text{ - say 2190 cubic inches void}$$

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A cross-sectional diagram of a dome structure. The dome is supported by a central rectangular pier and two side walls. The labels indicate the following components: (1) the left side wall, (2) the base of the left side wall, (3) the base of the central pier, (4) the top of the dome, and (5) the base of the right side wall.

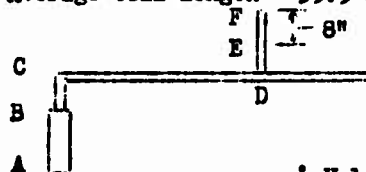
(2) Cylindrical part -

$$(3) V = \frac{49\pi}{4} \times 2 = 77 \text{ cubic inches}$$

$$\begin{array}{r} \text{Total vol.} = (1) + (2) - (3) - (4) = 1925 \\ \quad \quad \quad \underline{378} - \quad \quad \underline{33} \\ \quad \quad \quad 2303 \\ \quad \quad \quad \underline{110} \\ \quad \quad \quad 2193 \end{array} \quad \begin{array}{l} 77 \\ 33 \\ 110 \end{array}$$

say 2200 cubic inches

Average coil length = 35.5 feet overall = A to F



.'. BCDE = 35.5' - 18-1/4"
 = 35.5' - 1.5' = 34 feet

$$\therefore \text{Vol. of BCDE} = 34 \times 12 \times \left(\frac{9}{16}\right)^2 \times \frac{\pi}{4} \times 28 = 2840$$

$$\text{Vol. of BA} = 10.25 \times 28 \times \left(\frac{7}{8}\right)^2 \frac{\pi}{4} = 172 \text{ cubic inches}$$

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Volume of Pancake Coils Contd.

Total tube vol. = $2840 + 172 = 3010$ cubic inches

Spacer volume = $\frac{3}{8} \times \frac{3}{8} \times 6 \frac{7}{8} \times \frac{3}{4} \times 84 = 60$ cubic inches

Tubes and spacers = 3070 cubic inches

Net compound volume = $10140 - 3070 = 7070$ cubic inches = 4.09 cu.ft.

Weight of compound = $4.09 \times 62.5 \times .7 = \underline{179 \text{ lbs/reactor}}$

Active Portion of Compound

Edge: Assume Salcomine within $1/2"$ of tubes will desorb

.A layer of compound $3/4"$ deep will be inert all around the walls.

Volume of this annulus = approx. $24\pi \times 21.375 = 1610$ cubic in.
less vol. of BA $\frac{170}{1440}$ cubic in.
inert

Center: Radius of inert core = 3"

Volume of annulus = $(6^2 - 3^2) \frac{\pi}{4} \times 21.375 = 453$ cubic inches

Volume of ED = $28 \times \left(\frac{6}{16}\right)^2 \frac{\pi}{4} \times 10" = 70$ cubic inches

Net volume = $453 - 70 = 383$ cubic inches inert

Total = $\frac{1440}{383}$
 $1823 = 1.1$ cubic feet

$1.1 \times .7 \times 62.5 = 48.3$ lbs. inert compound
say 49 lbs.

Effective compound = 179
 $\frac{-49}{130}$ lbs.

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Expected Reactor Performance

Reactor as designed contains 179 lbs. of saturated Salcomine of which 130 lbs. are effective.

Maximum Expected Production (for max. consumption of utilities)

Abs. temp. - 68°F at 105 lbs/sq.in.abs.
Desorb temp. - 212°F at atm.

Cycle

Abs.	- 6 min.
Des.	- 4 min.
Cool	- 2 min.
Vac.	- 1/2 min.
	12-1/2 min.

$$\text{frequency} = \frac{60}{12.5} = 4.8$$

Exit gas rate - 4 CFH/40.7 grams Salcomine @ 25°C and 1 atm.

Absorption = 3.47% from completely desorbed Salcomine
Desorption = 93%
Residual O₂ = 3.46 x .07 = 0.2
Net yield = 3.45%

$$\text{O}_2 \text{ production} = 130 \times 0.0345 \times 4 \times 4.8 = 86.1 \text{ lbs/hr}$$

$$\text{less void loss which} = 4.2 \times 0.065 \times 4 \times 4.8 = 8.1 \text{ lbs/hr}$$

$$\text{Net production} = (86.1 - 8.1) \times \frac{1000}{84.5} = \underline{925 \text{ CFH}}$$

$$\text{Air consumption} = 2 \left(\frac{179 \times 4.54}{40.7} \times 4 \times \frac{520}{537} \right) + 925 = 16385 \text{ CFH}$$

$$\text{O}_2 \text{ yield} = \frac{925}{16385 \times .21} \times 100 = 27\%$$

Cycle As Designed (12' total, 3 min. abs.)

Exit gas rate - 4 CFH/40.7 gr. Salcomine at 25°C

Absorption = 2.25%
Net yield = 2.23%

$$\text{O}_2 \text{ production} = 130 \times 0.0223 \times 20 = 58.0 \text{ lbs/hr}$$

$$\text{Void loss} = 4.2 \times .065 \times 20 = 5.5 \text{ lbs/hr}$$

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Cycle As Designed Contd.

$$\text{Net production} = 52.5 \times \frac{1000}{84.5} = 622 \text{ CFH}$$

$$\text{Air consumption} = \frac{179 \times 4.54}{40.7} \times 4 \times \frac{520}{537} + 622 = 8352 \text{ CFH}$$

$$\text{Oxygen yield} = \frac{622}{8352 \times .21} \times 100 = \underline{35\%}$$

Purity of Product

$$\begin{array}{rcl} \text{Volume of reactor shells} & = & 2300 \text{ cubic inches} \quad - \text{ upper head} \\ & + & \frac{2190}{4490} \text{ " " " } \quad - \text{ lower head} \\ & & \text{total} = 2.6 \text{ cubic feet} \end{array}$$

Most recent data at time of writing, October 5, 1942, indicates that Salcomine is 39% voids and weighs 42 lbs/cu.ft.

Volume of compound per reactor = 4.09 cubic feet

ρ_G = density of O_2 left in powder

Volume of gas in Salcomine voids = $4.09 \times .39 = 1.6$ cubic feet

Total volume of residual gas =

$$\text{vol. in voids} + \text{vol. in heads} = 1.6 + 2.6 = 4.2 \text{ cubic ft.}$$

Assume this gas is air because reaction rate is nearly zero at end of absorption.

$$\text{Nitrogen in residual gas} = (4.2) (.79) (\rho_G) \text{ lbs.} = 3.3 \rho_G$$

where ρ_G = air density in voids

$$\text{Oxygen evolved} = \frac{84.5}{20} \text{ lbs/hr} = 4.22 \text{ lbs/reactor per cycle}$$

$$\text{Approx. \% } N_2 \text{ in } O_2 = \frac{3.3 \rho_G}{4.2} 100 = \frac{330 \rho_G}{4.2} = 79 \rho_G$$

$$\rho_G \text{ at } 80^\circ \text{ and } 760 \text{ mmHg} = 0.076 \text{ lbs/cu.ft.}$$

$$\rho_G \text{ at } 80^\circ \text{ and any pressure (Pmm)} = 0.076 \times \frac{P}{760} =$$

For pressure after evacuation of Pmm, average % N_2 in O_2 is

$$\% N_2 = (79) \frac{(0.076)}{760} (P) = 0.0079 P$$

$$O_2 \text{ purity} = 100 - 0.0079 P$$

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Oxygen Losses in Voids

Total voids = 4.2 cubic feet

Density of O_2 at $100^\circ C$ and 1 atm. = 0.065 lbs/cu. ft.

Loss per hour = $4.2 \times 0.065 \times 20 = 5.46$ lbs/hr

O_2 product = 84.5 lbs/hr

% loss = $\frac{5.46}{84.5 + 5.46} 100 = 6.1\%$

Oxygen Coolers

Oxygen Cooler (between reactors and compressor) "C-1"

Duty - cooling 84.5 lbs/hr of O_2 from $210^\circ F$ to $100^\circ F$

h of O_2 at 210° and 1 atm. = 143.2 BTU/lb (G-605.30)*

h of O_2 at 100° and 1 atm. = $\frac{119.2}{24.0}$ " "

Total duty = $(24.0) (84.5) = 2030$ BTU/lb

Cooling medium - 85° water

Pressure drop in O_2 < 0.5 lbs/sq.in.

Oxygen Compressor Coolers "C-2" and "C-3"

Suction to 1st stage - $100^\circ F$ and 1 atm.

Discharge from 1st stage - $306^\circ F$ and 49.0 lbs/sq.in.abs.

Suction to 2nd stage - $100^\circ F$ and 49.0 lbs/sq.in.abs.

Discharge from 2nd stage - $306^\circ F$ and 165.0 lbs/sq.in.abs.

Suction to holder - $100^\circ F$ and 165.0 lbs/sq.in.abs.

Compressor discharge temperatures based on $n = 1.35$ instead of 1.40 to correct for non-adiabatic compression.

Cooling medium - 85° water C_p for $O_2 = 0.22$ BTU/ lb. $^\circ F$

Duty to C-2 cooler = $(84.5) (306 - 100) (0.22) = 5850$ BTU/hr

Duty to C-3 cooler = $(84.5) (306 - 100) (0.22) = 5850$ BTU/hr

Pressure drop in O_2 streams < 2.0 lbs/sq.in.

* Note: Number in parenthesis refers to chart in M. W. Kellogg Company Technical Data Book.

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Oxygen Compressor Coolers "C-2 and "C-3" Contd.

Total cooler duties -	C-1	2050
	C-2	3850
	C-3	3850
		9750 BTU/hr

Oxygen Holder

Description data from E.R. Gilliland on May 13, 1942
- 90° C from 35° C 3.57% absorbed

Time (g)	% Desorbed (P)	ΔP	$\Delta \theta$	$\Delta P / \Delta \theta$	$\frac{dP}{d\theta}$	$\frac{dP}{d\theta}$
0	0				0	16.7
1/2	4.0	4.0	1/2	8.0	14.8	30.5
1	13.5	9.5	1/2	19.0	21.9	36.9
1-1/2	26.0	12.5	1/2	25.0	25.2	39.4
2	39.4	13.4	1/2	26.8	22.4	34.8
2-1/2	48.1	8.7	1/2	17.4	18.3	27.4
3	56.7	8.6	1/2	17.2	18.7	21.7
3-1/2	65.5	8.8	1/2	17.6	15.7	
4	72.1	8.6	1/2	13.2	15.0	
4-1/2	82.8	10.7	1/2	21.4	14.2	
5	87.5	4.7	1/2	9.4	12.4	
5	87.5	8.7	1	8.7		
8	96.2				5.0	

Calculation of rate of oxygen evolution as a function of desorption time. $dP/d\theta$ by graphical differentiation.

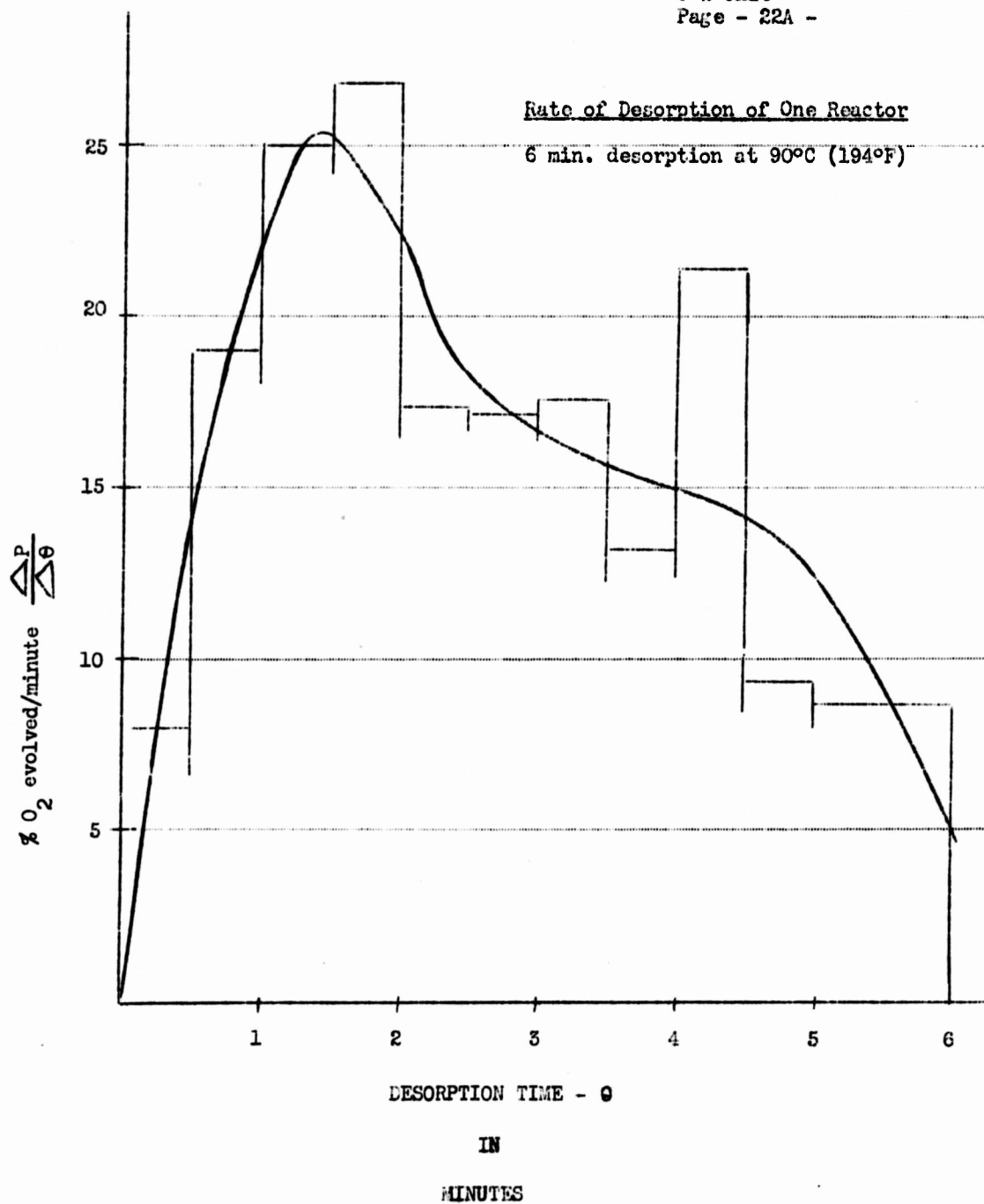
Col. 6 is table of values of $dP/d\theta$ for one reactor alone.

Col. 7 is table of values of $dP/d\theta$ for two reactors desorbing with three minutes overlap.

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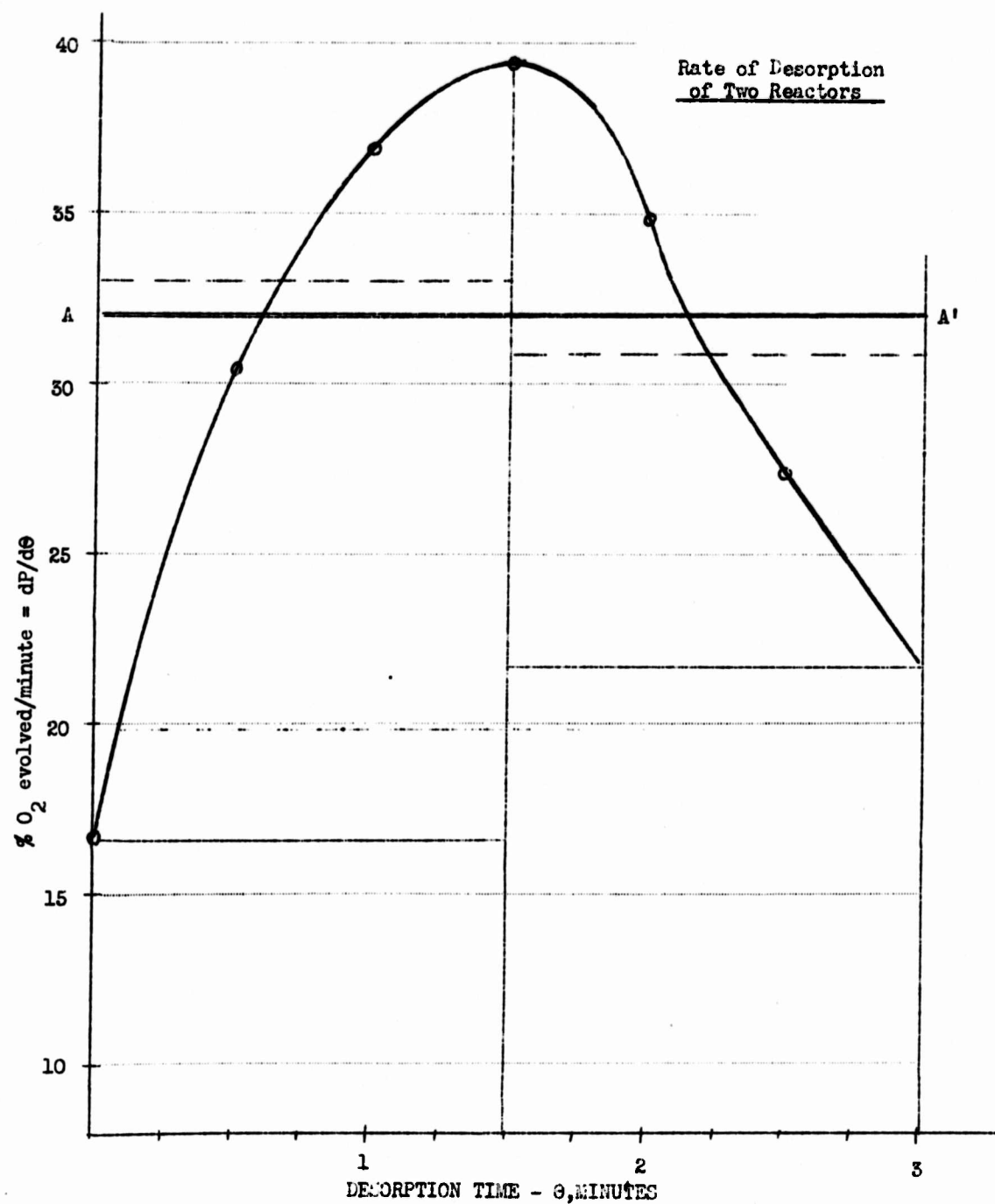
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Process Calculations

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Curve on page 22B is plot of rate of O_2 evolution (expressed as a percent) against time for two reactors desorbing on a three minute overlap. Data from Col. 7 page 22.

Average rate is about 32% in one minute as shown by line AA'.

Area above AA' is equal to 9% of area below AA', i.e., peak load to be carried by O_2 holder is 9% of total flow in three minutes.

Total flow in three minutes = $\frac{1000}{60} \times 3 = 50$ cubic feet

9% of 50 cubic feet = 4.5 cubic feet - theoretical holder volume.

Use a holder 18" in diameter and 5' long with internal volume of 8.5 cubic feet to allow 90% safety factor.

Heat Duty

Heat Duty to Reactors (for original cycle with 68° water)

Item	Heated Through Entire Temp. Range	Heated Through 55% of Temp. Range
Coils and fittings	185	
Flanges and bolts		160
Top head		60
Bottom head		50
Bottom header	75	
Top header	80	
Shell, core, screens		145
	290	415
	270	265
	560 lbs. total through entire temp. range	270 through entire range

Heat Duty

Heat of reaction $2.64 \times 19,000 \times 1.8 = 90,400$

Sensible heat to Salcomine
 $(179)(212 - 68)(0.25)(20) = 129,000$

Sensible heat to metal
 $(560)(212 - 68)(0.10)(20) = 161,000$
380,400 BTU/hr

Duty to O_2 coolers
9,750
Total duty 390,150 BTU/hr

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Process Calculations
C-2 Unit
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Cooling Water System

Ave. temp. change in water $\sim 10^\circ \text{ F}$

$$\text{Water rate} = \frac{580,400}{10 \times 60} = 967 \text{ lbs/min.} = \underline{78 \text{ GPM}}$$

Fresh water cooler "C-4"

Duty - 400,000

Fresh water rate - 80 GPM

Fresh water temp. change - 10°

Temp. approach - 10° between sea water in and fresh water out

Sea water rate - 160 GPM

Sea water temp. change - 5°

Fresh water pump "J - 4" to deliver 80 GPM at room temp. and
80 lb/sq.in. ga. discharge pressure

Steam System

Heat duty to steam = reactor duty only = 580,400 BTU/hr

Assuming latent heat of steam at 1000 BTU/lb,
steam consumption =

$$\frac{580,400}{1000} = \underline{580 \text{ lbs/hr}}$$

say 400

Analysis of Dryer Heat Loads

Dryer Weight.

Assume shell is $5/16"$ thick \times $7-5/4"$ ID \times 38" tall

$$\text{Shell weight} = \frac{5}{16} \times \left(7 \frac{5}{4} + \frac{5}{16} \right) \times 38 \times 0.28 \text{ lbs/cu.ft.} \times \pi = 50 \text{ lbs.}$$

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Dryer Weight Contd.

$$\text{Weight of head} = (11 \frac{5}{8})^2 \frac{\pi}{4} \times \frac{5}{8} \times 0.28 = 18 \text{ lbs.}$$

$$\text{Wt. of bottom} = (8 \frac{1}{8})^2 \frac{\pi}{4} \times \frac{5}{8} \times 0.28 = 9 \text{ lbs.}$$

$$\text{Wt. of flange} = (11 \frac{5}{8}^2 - 8 \frac{1}{8}^2) \frac{\pi}{4} \times \frac{5}{8} \times 0.28 = 9 \text{ lbs.}$$

$$\text{Bolts} = 10 \text{ lbs.}$$

$$\text{Screens} = \frac{4 \text{ lbs.}}{100 \text{ lbs.}}$$

Alumina volume without inner insulation:

$$\left(7 \frac{3}{4}\right)^2 \frac{\pi}{4} \times 52" = 1510 \text{ cubic inches} = 0.875 \text{ cubic feet}$$

$$\text{Wt. of alumina} = 0.875 \times 50 = 43.8 \approx \underline{44 \text{ lbs.}}$$

Heat Duty No insulation

Final alumina temp. = 500°F after heating

Initial alumina temp. = 100°F after cooling

Atmosphere temp. = 80°F

$$\text{Thermal conductivity of steel} = k = 26 \frac{\text{BTU}}{(\text{hr})(\text{sq.ft.})(^\circ \text{F})/\text{ft.}}$$

$$R_{\text{steel}} = \frac{L}{kA} = \frac{\frac{5}{8} \times \frac{1}{12}}{26 \times 1} = 0.0012 \frac{(\text{hr})(^\circ \text{F})}{(\text{BTU})(\text{sq.ft.})}$$

$$\text{For air film } (h_r + h_c) = 4 \frac{\text{BTU}}{\text{hr.}^\circ \text{F sq.ft.}} \text{ Perry, 2nd ed. page 987 table 14}$$

$$R_{\text{film}} = \frac{1}{hA} = \frac{1}{4 \times 1} = 0.25 \frac{\text{hr.}^\circ \text{F}}{(\text{BTU})(\text{sq.ft.})}$$

$$\text{Total resistance} = 0.25 + 0.0012 = 0.2512$$

$$\text{Total } \Delta T = 500^\circ \text{F} - 80^\circ \text{F} = 420^\circ \text{F}$$

$$\Delta T \text{ through steel} = 420 \times \frac{0.0012}{0.2512} = 2^\circ \text{F}$$

$$\therefore \text{average final steel temp.} = 500^\circ \text{F} - \frac{2}{1} = 498^\circ \text{F. say } 500^\circ \text{F}$$

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Water Absorption (1 hr. cycle, 30 minutes drying)

Air dew point = 80°F

Vapor pressure of water @ 80°F = 0.5067 lbs/sq.in.

Partial pressure of dry air at 1 atm. = 14.7 - 0.5067 = 14.2 lbs/sq.in.

Partial pressure of dry air at 105 psia = 105 - 0.5067 = 104.5 lbs/sq.in.

Water content of saturated air at 1 atm. = 0.02226 lbs water/lb. dry air (from tables)

Water content of air at 105 psia =

$$0.02226 \times \frac{14.2}{104.5} = 0.00302 \text{ lbs water/lb dry air}$$

Design air flow rate = 875 lbs/hr.

Design water input = 875 x 0.00302 = 2.64 lbs water/hr.

Water absorbed per cycle = 1.32 lbs.

$$\frac{1.32 \times 100}{44} = 3\% \text{ saturation on alumina}$$

Heat Leak

Initial ($h_c + h_r$) = 2

Final ($h_c + h_r$) = 4

Average = 3 BTU/hr.sq.ft.°F

Dryer Surface Area =

<u>End</u>	8 1/8" dia.	= 0.3600 sq.ft.
<u>Top</u>	11 3/8" dia.	= 0.7050 " "
<u>Top edge</u>	1 1/4" x 11 3/8" x π x 1/144	= 0.3100 " "
<u>Top flange</u>	0.7050 - 0.3600	= 0.3450 " "
<u>Side</u>	8 1/8" x π x 58 x 1/144	= 6.55 " "
		8.2700 sq.ft.

say 8.3 sq.ft.

Initial temp. difference = 20°

Final temp. difference = 420°

Mean ΔT = 220°F

Heat leak = ($h_c + h_r$) $A \Delta T$ = (3)(8.3)(220) = 5500 BTU/hr

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Heat Leak Contd.

Add 25% for safety \Rightarrow heat leak = 7000 BTU/hr
and for 15 min. = 1700 BTU

Total Heat Duty (one cycle)

To H ₂ O	= 1.32 x 1000	1320 BTU
To alumina	= (44)(500-80)(0.20)	3700
To metal	= (100)(500-80)(0.12)	5020
To heat leak	=	1700
		<u>11740 BTU in 15 min.</u>

$$\text{Power rate} = \frac{11740 \times 4}{3420} = 14 \text{ KW}$$

Insulated Dryer

Use lead slag wool inside shell so that alumina bed dia. = 6"

$$\text{New alumina volume} = 6^2 \frac{\pi}{4} \times 32 = 906 \text{ cu.in.} = 0.523 \text{ cu.ft.}$$

$$\text{Weight of alumina} = 0.523 \times 50 = 26 \text{ lbs.}$$

Water Absorption

$$\text{In 30 minutes} = 1.32 \text{ lbs.}$$

$$\% \text{ saturation} = \frac{1.32 \times 100}{26} = 5.1\% \text{ OK}$$

$$\text{Wt. of insulation (12 lbs/cu.ft.)} = \left[\left(7 \frac{3}{4} \right)^2 - (6)^2 \right] \frac{\pi}{4} \times \frac{32}{1728} \times 12 = 4.2 \text{ lbs.}$$

$$\text{Heat capacity} = 0.22 \frac{\text{BTU}}{(\text{lb.})(^{\circ}\text{F})}$$

Temperature Differences

$$k \text{ for lead slag wool} = 0.022 \frac{\text{BTU}}{\text{hr.sq.ft.}^{\circ}\text{F/ft.}} \quad \Delta 35^{\circ}\text{F}$$

Use 0.026 to correct for effect of higher temperature.

$$\text{Depth of insulation} = 7/8" = 0.075 \text{ ft.} = L$$

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Temperature Differences Contd.

$$\text{Inside insulation area} = \frac{8\pi \times 82}{144} = 4.18 \text{ sq.ft.}$$

$$\text{Outside insulation area} = \frac{7.5/4 \pi \times 82}{144} = 5.40 \text{ sq.ft.}$$

$$\text{Log mean area} = 4.8 \text{ sq.ft.}$$

(E-1.501)

$$R_i = \text{resistance of insulation} = \frac{L}{kA} = \frac{0.075}{0.026 \times 4.8} = 0.585 \frac{\text{hr.}^\circ\text{F}}{\text{BTU}}$$

$$R_t (\text{through shell}) = R_{\text{film}} + R_m + R_i = 0.25 + 0.0012 + 0.585 = 0.8362$$

(Note: Neglecting effect of changes in area on metal and film resistances)

$$\text{Total } \Delta T = 500 - 80 = 420^\circ$$

$$\Delta T_m = 420 \times \frac{0.0012}{0.8362} = 0.60^\circ\text{F}$$

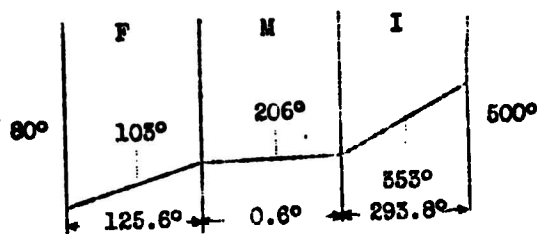
$$\text{Mean } T_m = 206^\circ$$

$$\Delta T_{\text{film}} = 420 \times \frac{0.25}{0.8362} = 125.6^\circ\text{F}$$

$$\text{Mean } T_f = 105^\circ$$

$$\Delta T_i = 420 \times \frac{0.585}{0.8362} = \frac{293.8^\circ\text{F}}{420.0^\circ\text{F}}$$

$$\text{Mean } T_i = 353^\circ$$



Heat Leak From Shell

Initial film $\Delta T = (\text{say}) 5^\circ$
Final film $\Delta T = 125.6^\circ$

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Heat Leak From Shell Contd.

$$\text{Mean } \Delta T = \frac{125.6 + 5}{2} = 66^\circ$$

$$(h_c + h_r) = 2 \quad (\Delta T \text{ calculated from } (h_c + h_r) = 4)$$

Revised ΔT 's

$$\text{Assume } (h_c + h_r) = 2.4$$

$$\therefore R_f = \frac{1}{2.4 \times 1} = 0.417$$

$$R_t = 0.417 + 0.0012 + 0.585 = 1.0032$$

Final Temp.

$$\Delta T_f = 420 \times \frac{0.417}{1.0032} = 174.5^\circ$$

$$\text{Mean } T_f = 167^\circ$$

$$\Delta T_m = 420 \times \frac{0.0012}{1.0032} = 0.50^\circ$$

$$\text{Mean } T_m = 254.5^\circ$$

$$\Delta T_i = 420 \times \frac{0.585}{1.0032} = 245.2^\circ$$

$$\text{Mean } T_i = 377^\circ$$

Revised Heat Leak

$$\text{Mean } \Delta T = \frac{174 + 5}{2} = 90^\circ$$

$$\text{Mean } (h_c + h_r) = \text{say } 2 \\ (= 5.68 \text{ sq.ft.})$$

$$\text{Heat leak} = (2) \left(6 \frac{1}{8} \pi \times \frac{52}{144} \right) (90) = 1020 \text{ BTU/hr through shell}$$

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Revised Heat Leak Contd.

Assume that rate of heat leak through remainder is at same rate as in uninsulated case.

$$\text{Remaining area} = 8.27 - 5.68 = 2.59 \text{ sq.ft.}$$

$$\text{Heat leak} = (5)(2.59)(220) = 1710 \text{ BTU/hr}$$

$$\begin{array}{r} \text{Total} \quad + \quad 1020 \\ \hline 2730 \quad " \quad " \end{array}$$

$$\text{for 15 min. leak} = \frac{2730}{4} = 680 \text{ BTU}$$

Heat Duty

$$\text{To H}_2\text{O} = 1.32 \times 1000$$

1520

$$\text{To alumina} = (26)(500-80)(.20)$$

2160

$$\text{To metal} =$$

$$\text{shell} - (50)(254.5-80)(0.12)$$

1050

$$\text{heads, etc.} (50)(500-80)(0.12)$$

2520

$$\text{To insulation} (4.2)(352-80)(0.22)$$

252

$$\text{To heat leak}$$

680

8002 BTU in 15 min.

$$\text{Power rate} = \frac{8002 \times 4}{5420} = 9.56 \text{ KW}$$

$$\text{Safety factor} = \frac{10-9.56}{10} \times 100 = 6.4\%$$

Utilities & Supplies

Steam

Low pressure - 400 lbs/hr

High pressure (150 lb)-

20 lbs/hr @ rate of 100 lbs/hr

Sea Water

160 gals/min @ 80 lb/sq.in. ga. pressure

Air

At 90 lbs/sq.in.gage - 16400 CFH max.

Electricity

230 v 60 cycle AC, 10 KW

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Process Calculations
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Fresh Water

150 gals. in system

Salcomine

720 lbs.

Alumina

80 lbs.

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INDEX OF DRAWINGSShipboard UnitM. W. Kellogg Company Drawings

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15-A	5/26/42	Layout of Piping
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25-A	5/26/42	Flow Diagram
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MWK-A006	9/30/42	MWK Pneumatic Interval Timer-Compound Gearing
Part MWK-5A1-10	10/1/42	Interval Timer Drum (36 functions)
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INDEX OF DRAWINGS CONTD.Shipboard UnitWhitlock Manufacturing Company Drawings

<u>Drawing #</u>	<u>Date</u>	<u>Title</u>
L-9994-A-1	5/25/42	30" OD Fabricated Steel Top Head
L-9994-B-1	5/25/42	Fabricated Steel Bottom Header
B-9994	5/26/42	Flat Spiral Coil Type Reactor
*A-1	2/4/43	"Lobo Job" Reactor Alteration
*1	2/4/43	Top Head Flange (Lobo Job)
*2	2/4/43	Top Head Stuffing Box Body (Lobo Job)
*3	2/4/43	Bottom Head Stuffing Box Body (Lobo Job)
*4	2/4/43	Stuffing Box Gland (Lobo Job)
*5	2/4/43	Stuffing Box Parts List

*Note: These drawings bear the Whitlock Title Box corrected to read "AMD Co.". They were prepared at the Whitlock plant by an engineer from the American Machine Defense Corporation.

Clark Brothers Company Drawings

105-48	8/1/42	2 State Vertical Compressor
105-50	8/17/42	Motor Driven 2 Stage Comp. Unit

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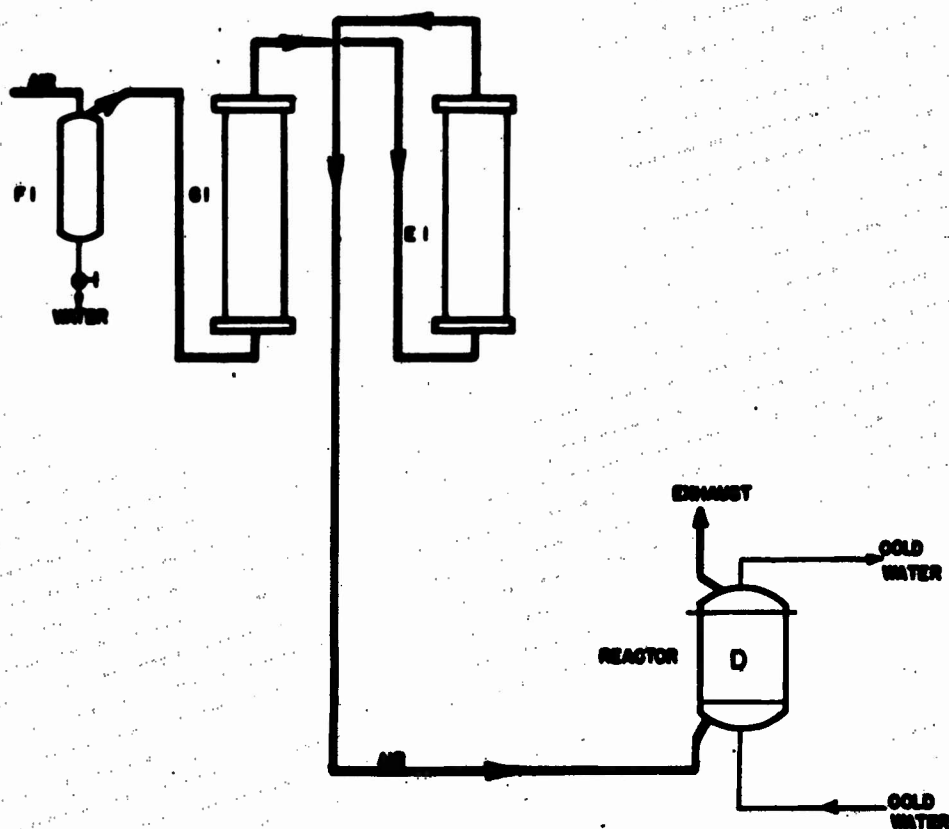
Schematic Flow Sheets and Sketches

Following pages contain schematic flow sheets of the basic stages in the operation of the Shipboard unit. There is also appended a sketch of the automatic timer which actuates the valves controlling the various gas and liquid streams in the unit.

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ABSORPTION FLOW SHEET I



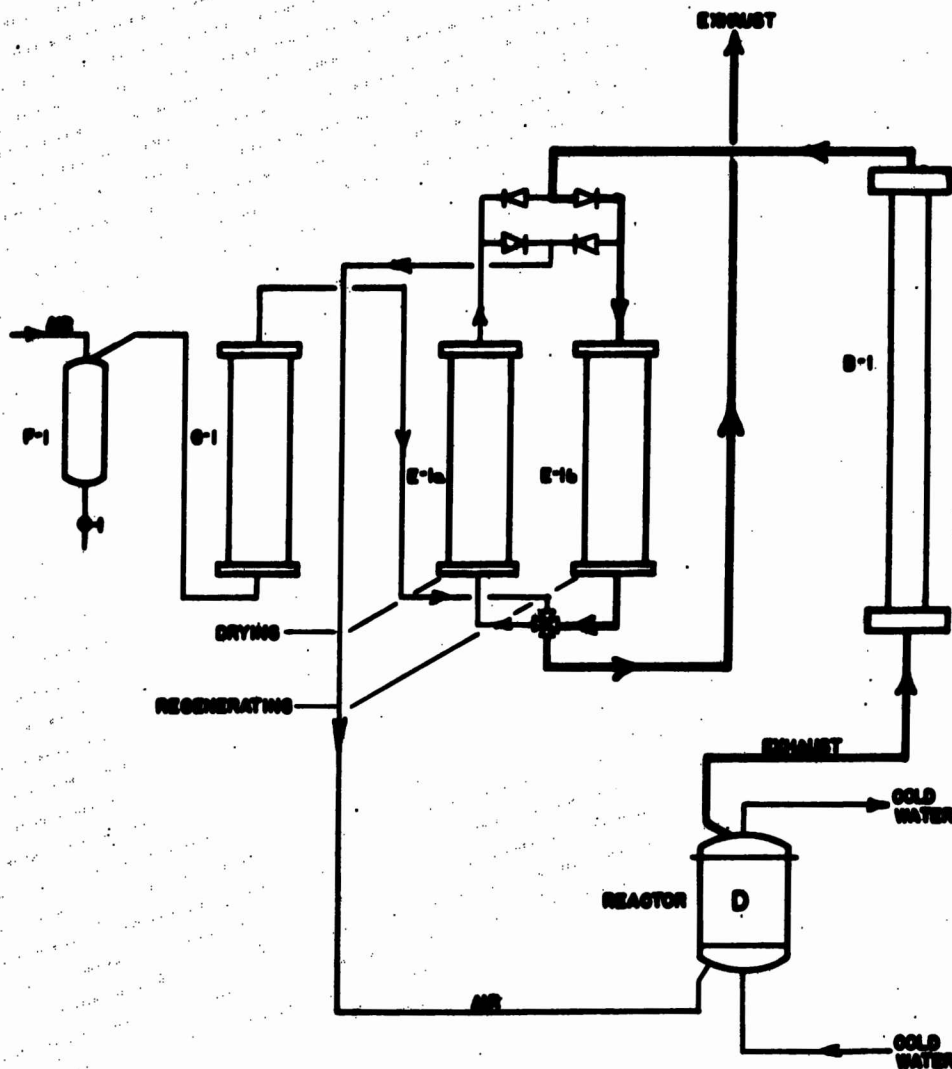
This portion of the flow sheet shows the course taken by the compressed air in passing through the drip drum, oil filter and reactor during an absorption period. During this time cold water is flowing through the reactor coils.

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ABSORPTION FLOW SHEET II

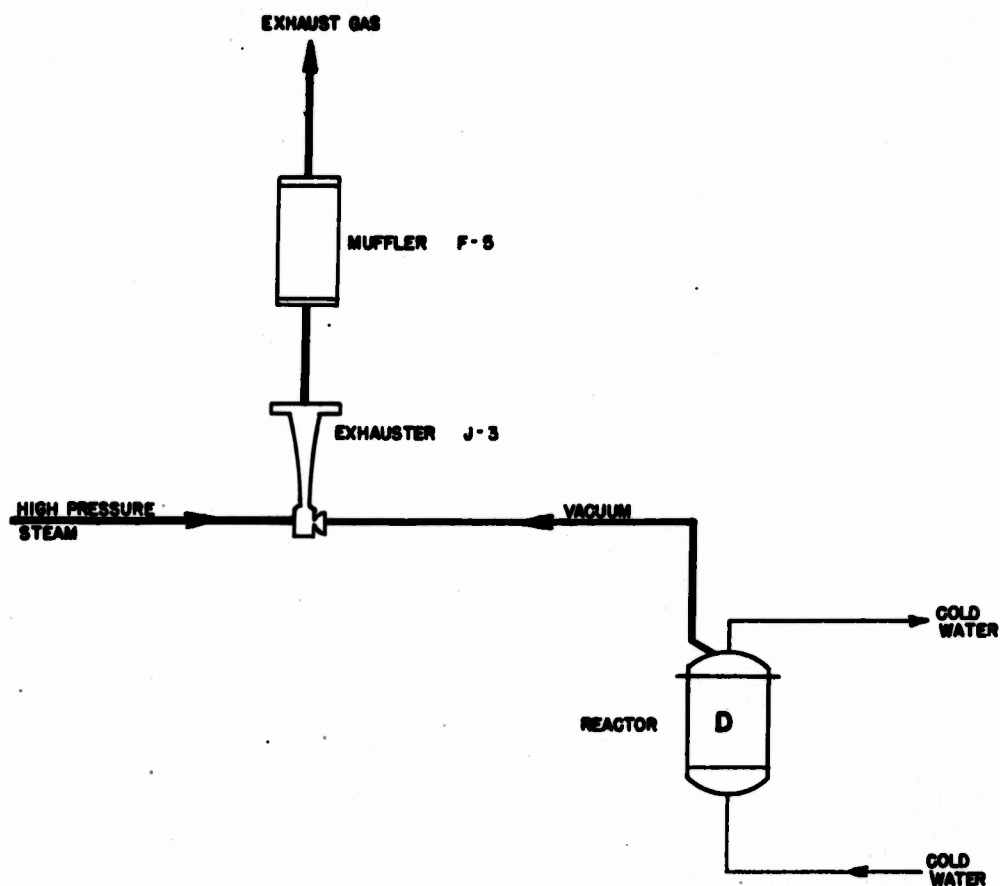


In addition to the items shown on Absorption Flow Sheet I, this flow sheet indicates the path of the reactor exhaust gas through the heater and the dryer which is being regenerated.

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EVACUATION FLOW SHEET

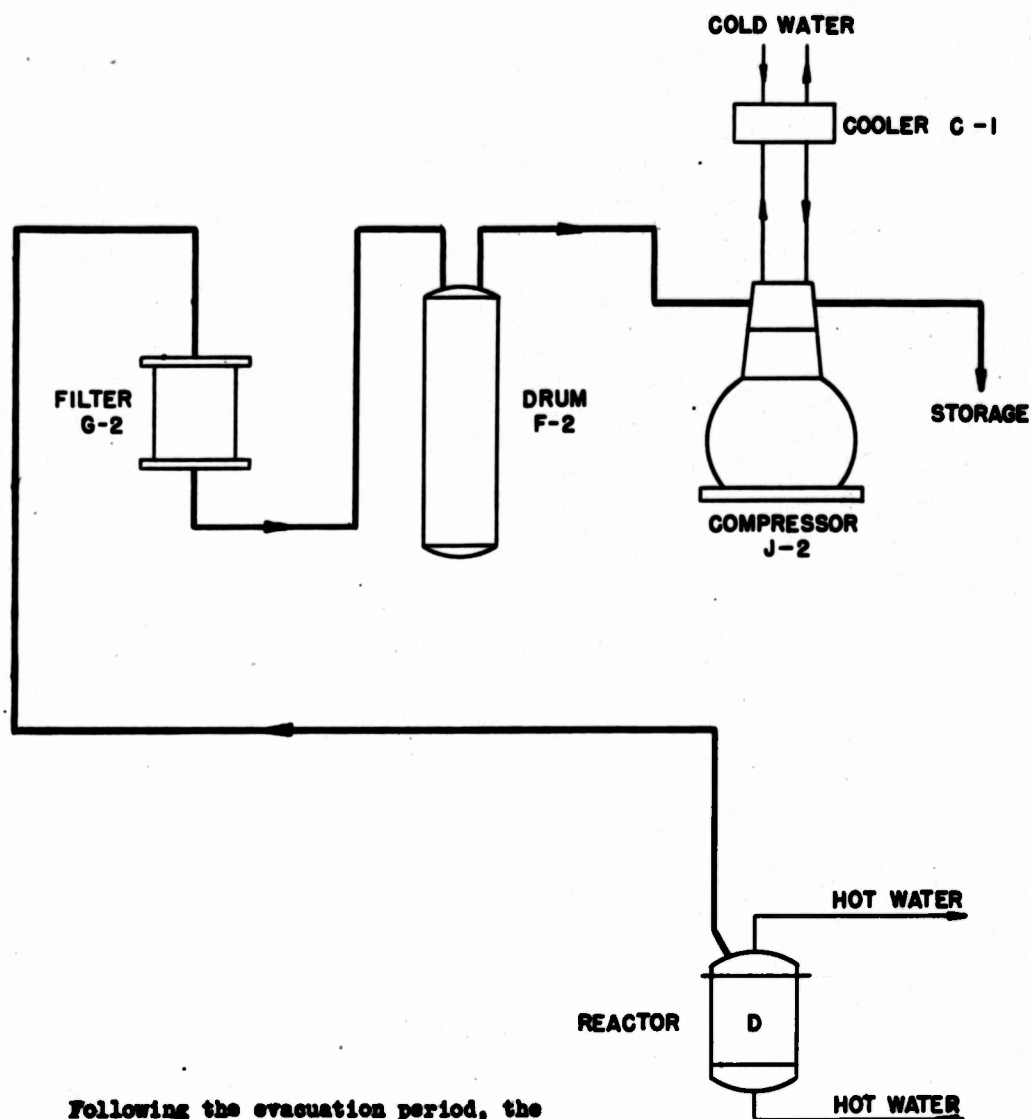


At the end of the absorption period the compressed air is sent to another reactor, and the reactor which has finished absorption is evacuated by means of the exhauster as shown above. Cold water continues to flow through the reactor coils.

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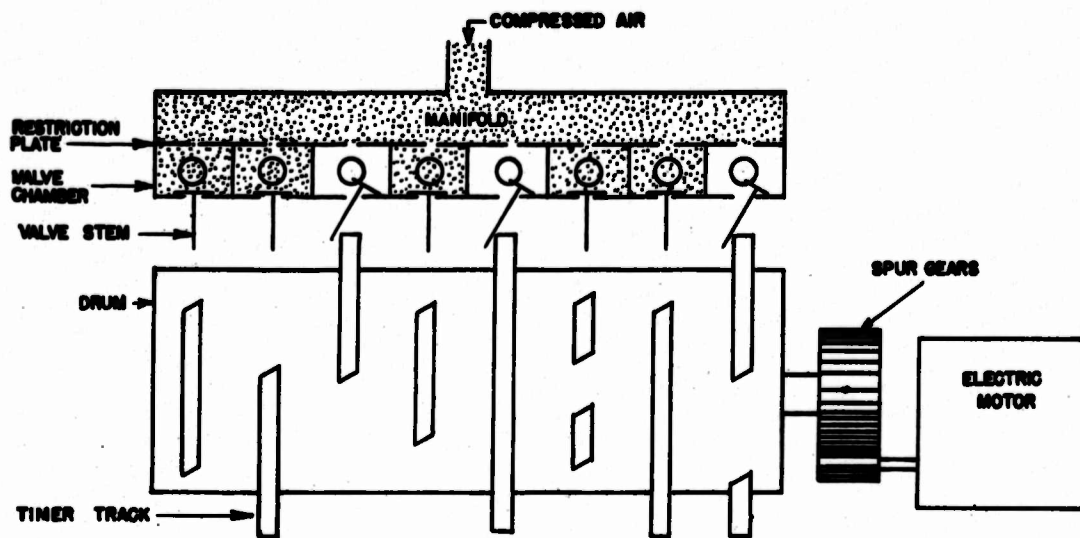
DESORPTION FLOW SHEET



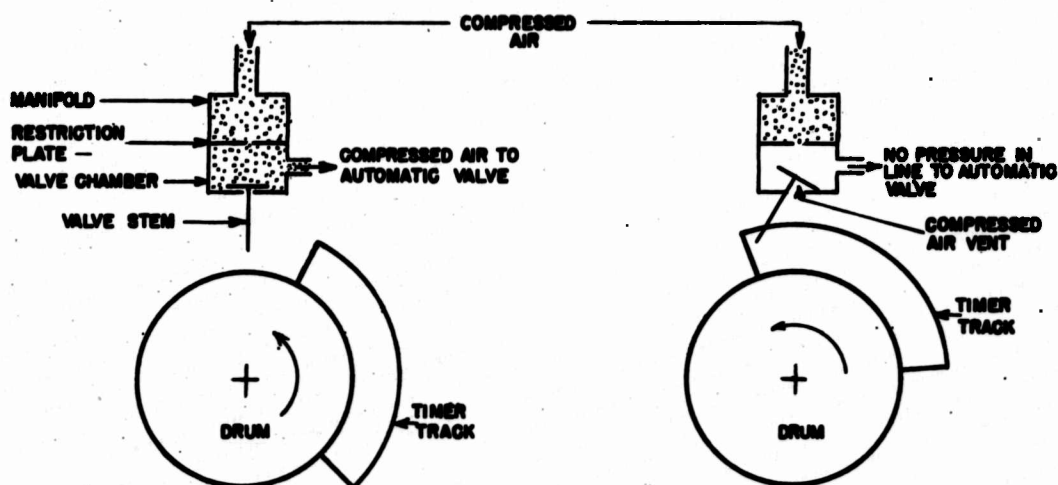
Following the evacuation period, the
exhauster is disconnected from the reactor
and hot water is sent through the reactor coils. Oxygen is given
off and flows through the filter to the drum and the compressor.
Here it is compressed and delivered to storage tanks or cutting
torches.

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AUTOMATIC TIMER



FRONT VIEW



PIN VALVE SHUT

SIDE VIEW

PIN VALVE OPEN

REEL - C

1 3 15

A.I.I.

3 1 6 4 5

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TITLE: Final Report on Oxygen Plant Development (Employing Regenerative Chemicals)

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A description is given of oxygen generating plants utilizing the absorbent "Salcomine". The plants were designed by the M. W. Kellogg Co., and such construction as took place was done by the American Machine Defense Corporation. In addition to a chronological description of each plant or study involved in the program, the report contains a bibliography of correspondence, memoranda, reports and specifications dealing with equipment details and operating experiments. Detailed process calculations and a list of all drawings are supplied for the Shipboard (C-2) unit, the only complete unit fabricated by the contracting companies. Process calculations and detailed designs are not furnished for plants which were studied but not erected.

DISTRIBUTION: Copies of this report obtainable from CADO

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~~George R Jordan, USCO~~
Signature and Grade

8 Aug 49

(23) * Oxygen generators

(25) Salcorine

p23/05